Robotics Final 2016

Q1

1. Discuss the advantages and disadvantages of using robot in industry?

Advantages

1. Environment safety
   ↳ robot can work in hard environments.
2. Productivity Parameter
   ↳ time to ~~make~~ get work done with robot is ~~be~~ better than human.
3. unit cost in the long run and batch
4. Accuracy, repeatability and work quality.

Disadvantages

1) Cost constraint in investment.
   ↳ (buying robot and its training and maintanence) is expensive.
2) Decision intelligence
   ↳ It can't think like human.
3) Replacement of labour in a populated place.
4) Real time response (slow)

2. What is workspace? Give the functional diagram with the workspace for the following robots

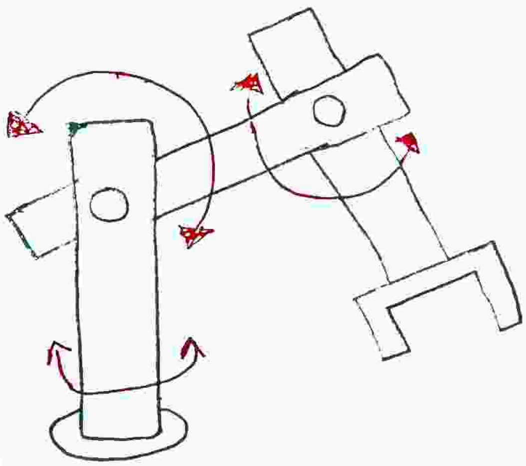
i) 3R-robot. ii) 2RP robot.

<u>workspace</u>

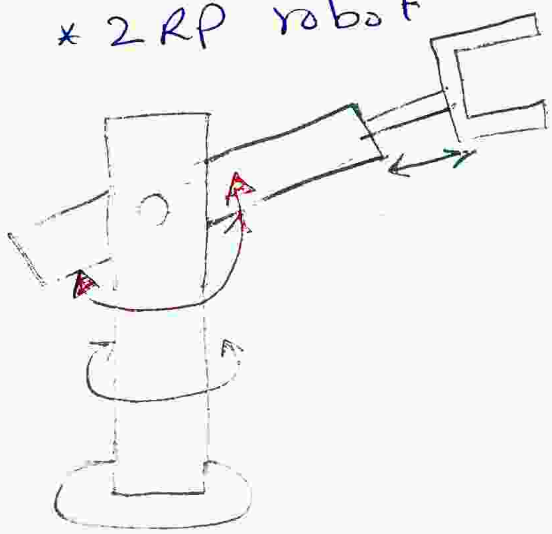
↳ set of points that can be reached by its end-effector

↳ The space in which mechanism is working

* 3R-robot.



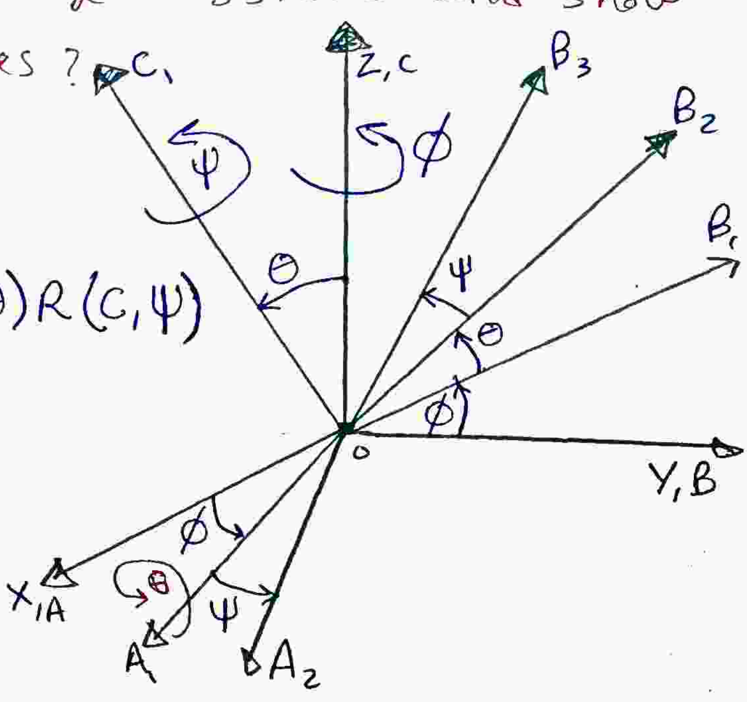
* 2RP robot



3. Draw any two Euler angle systems and show rotations and angles?

system 1 of Euler angles

$$R(\phi,\theta,\psi)_1 = R(z,\phi)R(A,\theta)R(C,\psi)$$



$$R(\phi,\theta,\psi)_1 =$$

$$\begin{bmatrix} c\phi & -s\phi & 0 \\ s\phi & c\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & c\theta & -s\theta \\ 0 & s\theta & c\theta \end{bmatrix} \begin{bmatrix} c\psi & -s\psi & 0 \\ s\psi & c\psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Where $c \Rightarrow \cos$ & $s \Rightarrow \sin$

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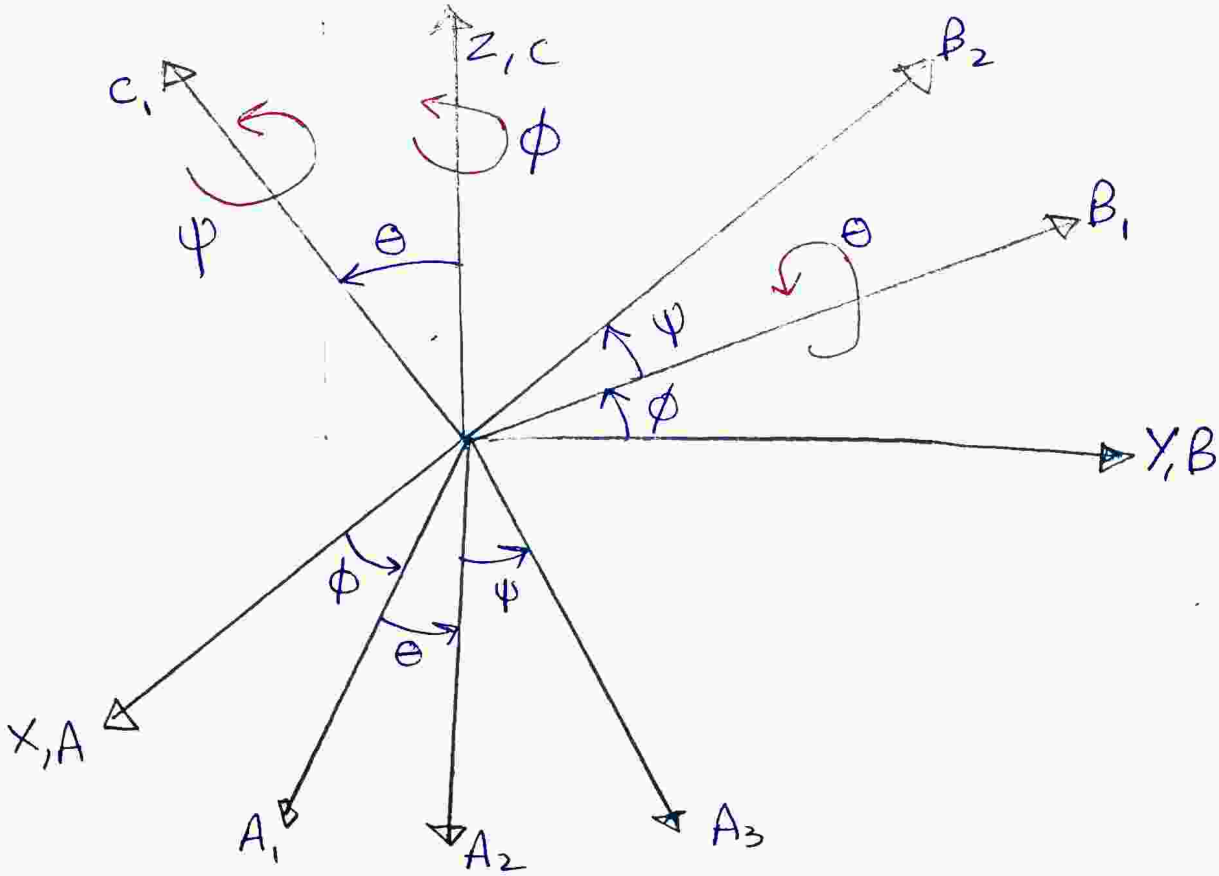
* system II of Euler angles.



$$R(\phi,\theta,\psi)_{II} = R(Z,\phi)\, R(B,\theta)\, R(C,\psi)$$

$$\begin{bmatrix} c\phi & -s\phi & 0 \\ s\phi & c\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c\theta & 0 & s\theta \\ 0 & 1 & 0 \\ -s\theta & 0 & c\theta \end{bmatrix} \begin{bmatrix} c\psi & -s\psi & 0 \\ s\psi & c\psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

4. What are Performance Parameters? Define repeatability, resolution and accuracy.

↳ Manufacturing Constraints and design inevitability put some limitations on performance of the robots (these limitations are the performance parameters)

repeatability ⇒ measures the ability of the robot to position the tool tip in the same place repeatedly.

resolution ⇒ The least count of movement into which robot's work envelope can be divided to represent incremental or decremental steps.

Accuracy ⇒ measure of the robot's ability to orient and locate the tool tip at a desired target location in the prescribed work envelop.

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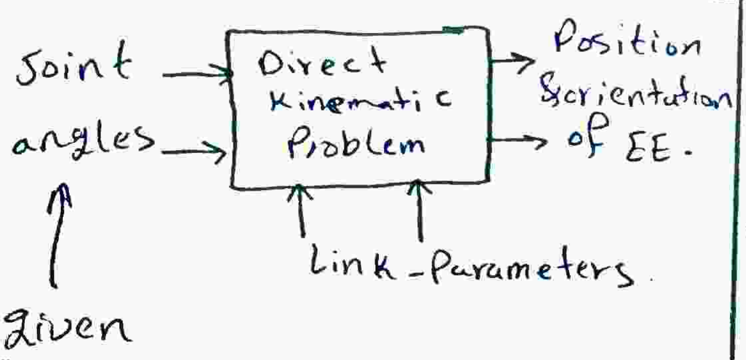
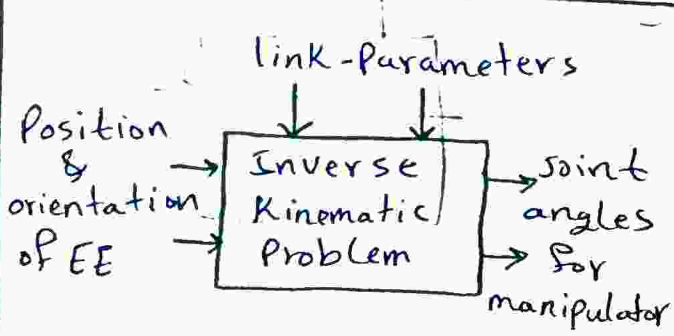
5. Define the term: Robot Kinematics?

↳ Description of motion of robot without consideration of forces and torques causing the motion.

6. Compare hard automation & soft automation

	Hard automation	soft automation
Cost effectiveness	Good for high Production volume	Good for moderate production volume
Flexibility	Limited	High
Batch Production	not suitable	Highly suitable
control throw SW.	not Possible	Easily possible
Effeciency of operation	Comparably high	equally high.

7 Differentiate between robot forward & inverse kinematics.

Forward	Inverse
↳ Determination of actual position & orientation of end-effector.	↳ Determination of values of joint variables.
• required to give feedback about end-effectors position	required to determine control actions.
	

8 mention the two DH assumptions for frame assignment in forward kinematics. Explain how they reduce the parameters required to relate frame i to frame $i-1$.

They are:

* DH1 - The axis x_i is perpendicular to axis z_{i-1}

* DH2 - The axis x_i intersects the axis z_{i-1}

⇒ Homogeneous transformation A_i represented by

* a_i : link length
* α_i : link twist.
* d_i : link offset
* θ_i : Joint angle

→ so the 6 parameters become only 4 parameters.

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9 In your own words, explain briefly how machine learning can be used to estimate robot inverse kinematics (explain steps of applying machine learning)

- ↳ one application of computational intelligence models such that fuzzy systems, Neural networks and ANFIS is to model systems described by non-linear functions.

- ↳ Parameters of these models are adjusted using machine learning techniques.

steps of apply machine learning.

1) Calculate Forward Kinematics.

2) Construct $f(q) = [X_{EE}, y_{EE}, \theta_{EE}]^T$

3) Apply Different values of θ_1, θ_2 and find corresponding $f(q)$ to form dataset.

4) Construct NN / ANFIS model with $[X_{EE}, y_{EE}, \theta_{EE}]$ as inputs and $[\theta_1, \theta_2]$ as outputs.

5) Apply machine learning technique (Back Propagation algorithm) using the data set to adjust model Parameters.

Question 2

① The co-ordinates of Point P_{abc} in mobile frame OABC is given by $[2,4,5]^T$, if the frame OABC is rotated by 45° w.r.t (OY) of frame OXYZ frame, find co-ordinates of P_{xyz} w.r.t base frame. $\theta = 45°$

$$P_{xyz} = R(Y, \theta)\, P_{abc}$$

$$= \begin{bmatrix} \overset{\frac{\sqrt{2}}{2}}{\cos(45)} & 0 & \overset{\frac{\sqrt{2}}{2}}{\sin(45)} \\ 0 & 1 & 0 \\ \overset{-\frac{\sqrt{2}}{2}}{-\sin(45)} & 0 & \overset{\frac{\sqrt{2}}{2}}{\cos(45)} \end{bmatrix} \begin{bmatrix} 2 \\ 4 \\ 5 \end{bmatrix} = [4.94, 4, 2.12]^T$$

Q2.2 A mobile body refrence frame OABC is rotated 30° about OZ-axis of the fixed base refrence frame OXYZ. if $P_{xyz} = [-1,2,3]^T$, $Q_{xyz} = [2,-3,1]^T$ are the coordinates w.r.t OXYZ plane, what are the corresponding coordinates of P and Q w.r.t OABC frame?

$$P_{abc} = R(Z,\theta)\, P_{xyz}$$

$$q_{abc} = R(Z,\theta)\, q_{xyz}$$

$$P_{abc} = \begin{bmatrix} \overset{\frac{\sqrt{3}}{2}}{\cos(30)} & \overset{-0.5}{-\sin(30)} & 0 \\ \sin 30 & \cos(30) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 \\ 2 \\ 3 \end{bmatrix} = [-1.86, 1.23, 3]$$

$$q_{abc} = \begin{bmatrix} \cos(30) & -\sin(30) & 0 \\ \sin(30) & \cos(30) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 2 \\ -3 \\ 1 \end{bmatrix} = [3.23, -1.59, 3]$$

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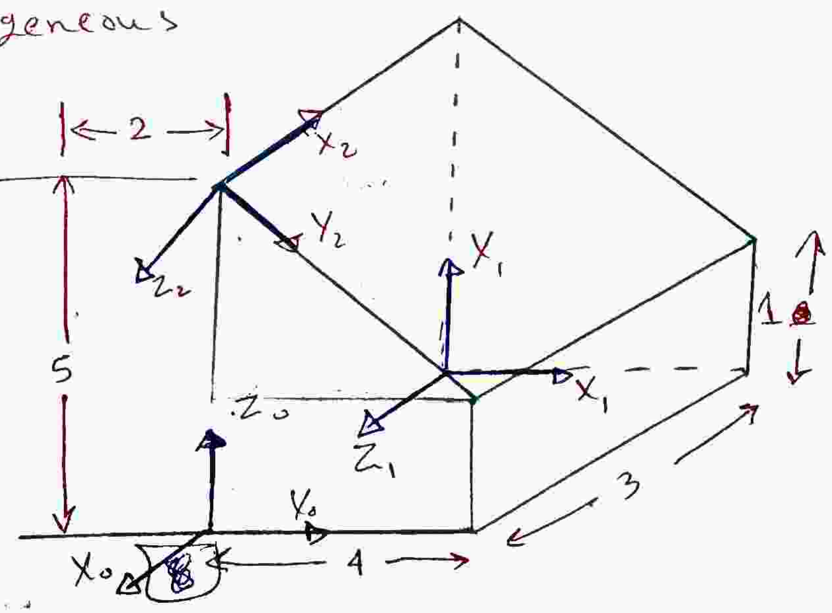
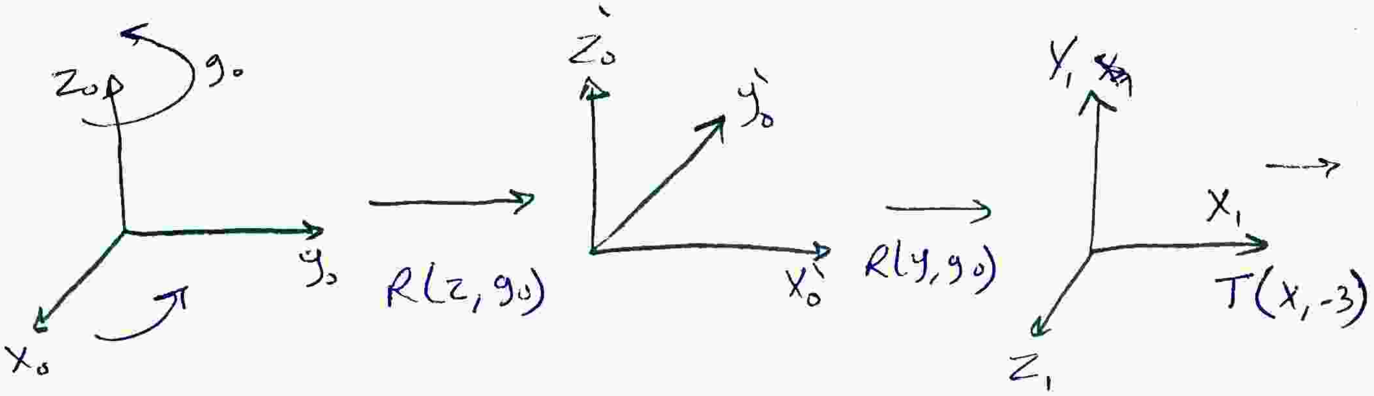
③ For object shown in figure find the 4×4 homogeneous transformation matrices ${}^{0}A_i$ for i=1,2 & find transformation of frame at point 1 w.r.t frame at point 2 (i.e ${}^{2}A_1$)



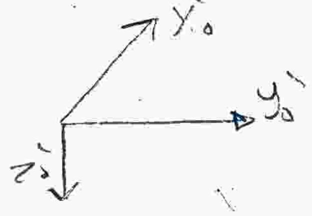


$${}^{0}A_1 = H(-3,0,0)\,R(Y_0,90)\,R(Z_0,90)$$

$$= \begin{bmatrix} 1 & 0 & 0 & -3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

${}^{0}A_2 \rightarrow$ requires

1) Rotation by 180° about Y_0 $\Rightarrow$



2) " " -45° about X_0 $\longrightarrow$

3) Transformation of (0, 0, 5)

$${}^{0}A_2 = H(0,0,5)\,R(X_0,-45)\,R(Y_0,180^\circ)$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 5 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(-45) & -\sin(-45) & 0 \\ 0 & \sin(-45) & \cos(-45) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \overset{\cos}{c(180)} & 0 & \overset{\sin}{s(180)} & 0 \\ 0 & 1 & 0 & 0 \\ -s(180) & 0 & c(180) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

ii) $^{1}A_2 = [^{0}A_1]^{-1} [^{0}A_2]$ من نتائج الصفحة السابقة

Question (3)

1) Determine homogeneous transformation matrix to represent a rotation of 30° about OZ-axis and translation of 20 units along OB-axis of mobile frame

$$H = R(Z,30) \cdot H(0,20,0)$$

$$= \begin{bmatrix} \cos(30) & -\sin(30) & 0 & 0 \\ \sin(30) & \cos(30) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 20 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \text{??}$$

2) Determine homogeneous transformation matrix to represent following sequence :

a) Rotation of 45° OZ-axis.

b) Translation of 4 units along OX-axis.

c) Translation of -4-units along OB-axis.

d) Rotation of 90° about OA-axis.

$$H = R(Z,45)\, H(4,0,0)\, H(0,-4,0)\, R(A,90)$$

$$R(Z,45) * R(A,90) = A_1 = \begin{bmatrix} \cos 45 & -\sin 45 & 0 & 0 \\ \sin 45 & \cos 45 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$* \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \overset{0}{\cos 90} & \overset{-1}{-\sin 90} & 0 \\ 0 & \sin(90) & \cos 90 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} \frac{\sqrt{2}}{2} & -\frac{\sqrt{2}}{2} & 0 & 0 \\ 0 & 0 & -1 & 0 \\ \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_2 = H(4,0,0)\, H(0,-4,0)$$

$$= \begin{bmatrix} 1 & 0 & 0 & 4 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & -4 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 4 \\ 0 & 1 & 0 & -4 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$H = A_1 * A_2$$

$$= \begin{bmatrix} \frac{\sqrt{2}}{2} & -\frac{\sqrt{2}}{2} & 0 & 0 \\ 0 & 0 & -1 & 0 \\ \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 4 \\ 0 & 1 & 0 & -4 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} \frac{\sqrt{2}}{2} & -\frac{\sqrt{2}}{2} & 0 & 4\sqrt{2} \\ 0 & 0 & -1 & 0 \\ \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$\boxed{Q_{3\text{-}3}}$ robotic workcell has camera with in the setup. The origin of six joint robot fixed to a base can be seen by camera. The homogeneous transformation matrix H_1 maps the camera with the cube center. The origin of the base co-ordinate system as seen from camera is represented by H_2

$$H_1 = \begin{bmatrix} 0 & 1 & 0 & 2 \\ 1 & 0 & 0 & 1 \\ 0 & 0 & -1 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad H_2 = \begin{bmatrix} 1 & 0 & 0 & -4 \\ 0 & -1 & 0 & 2 \\ 0 & 0 & -1 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

a) what is position & orientation of cube with respect to base co-ordinate system?

$$^{camera}H_{cube} = H_1 \quad , \quad ^{camera}H_{base} = H_2$$

$$^{base}H_{cube} = {}^{base}H_{camera} \cdot {}^{camera}H_{cube} = (H_2)^{-1} H_1$$

$$= \begin{bmatrix} 1 & 0 & 0 & 4 \\ 0 & -1 & 0 & -2 \\ 0 & 0 & -1 & -3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & 1 & 0 & 2 \\ 1 & 0 & 0 & 1 \\ 0 & 0 & -1 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix} =$$

$$\begin{matrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{matrix} \qquad = \begin{bmatrix} 0 & 1 & 0 & 6 \\ -1 & 0 & 0 & -3 \\ 0 & 0 & 1 & -6 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad [6, -3, 6] \rightarrow \text{Position of cube}$$

↳ orientation

$\boxed{\text{Note}}$

How to get H^{-1}

هتدورها   هتضربهم في سالب

$$H = \left[\begin{array}{c|c} R(3*3) & \begin{array}{c} P \\ (3\times1) \end{array} \\ \hline 0 \quad 0 \quad 0 & 1 \end{array}\right] \Rightarrow H^{-1} = \left[\begin{array}{c|c} R^T & -R^T P \\ \hline 0 \quad 0 \quad 0 & \end{array}\right]$$

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b) After system has been setup, someone rotates the Camera 90 about X-axis of Camera, what is the Position and orientation of the Camera with respect to robot's base co-ordinate system?

$$^{base}H_{Camera} = (H_2)^{-1}\, H(X, 90)$$

$$= \begin{bmatrix} 1 & 0 & 0 & 4 \\ 0 & -1 & 0 & -2 \\ 0 & 0 & -1 & -3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \overset{0}{\cos 90} & \overset{-1}{-\sin 90} & 0 \\ 0 & \overset{1}{\sin 90} & \overset{0}{\cos 90} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & 0 & 4 \\ 0 & 0 & 1 & -2 \\ 0 & -1 & 0 & -3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Position $\Rightarrow [4, -2, -3]$

orientation

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & -1 & 0 \end{bmatrix}$$

c) The same person rotated by 90 the object about Z-axis of the object and translated 5 units of distance along the rotated Y-axis. what is the position and orientation of the object with respect to the robot's base Co-ordinate system?

$$^{b}H_{c} = {}^{base}H_{cube} * H(Z,90) * H(Y,5)$$

$$= \begin{bmatrix} 0 & 1 & 0 & 6 \\ -1 & 0 & 0 & -3 \\ 0 & 0 & 1 & -6 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(90) & -\sin(90) & 0 & 0 \\ \sin 90 & \cos 90 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 5 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \checkmark$$

Question 4

* A six joint robotic manipulator equipped with digital TV camera is capable of continuously monitoring position and orientation of an object. The position and orientation of object w.r.t camera is expressed by matrix $[T_1]$, The origin of robot's base coordinate w.r.t camera is given by T_2, and position and orientation of gripper w.r.t base coordinate is T_3

$$T_1 = \begin{bmatrix} 0 & 1 & 0 & 3 \\ 1 & 0 & 0 & 2 \\ 0 & 0 & -1 & -1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \; \& \; T_2 = \begin{bmatrix} 1 & 0 & 0 & -2 \\ 0 & -1 & 0 & 2 \\ 0 & 0 & -1 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \; \& \; T_3 = \begin{bmatrix} 1 & 0 & 0 & 2 \\ 0 & 1 & 0 & 4 \\ 0 & 0 & 1 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Determine

i) Position & orientation of object w.r.t bast Co-ordinate.

ii) " & " of object w.r.t gripper.

given

$$T_1 = {}^{camera}T_{object} \quad \& \quad T_2 = {}^{camera}T_{base} \quad \& \quad T_3 = {}^{base}T_{gripper}$$

i)
$$ {}^{base}T_{object} = {}^{base}T_{camera} * {}^{camera}T_{object} = (T_2)^{-1} * (T_1)$$

$$= \begin{bmatrix} 1 & 0 & 0 & 2 \\ 0 & -1 & 0 & -2 \\ 0 & 0 & -1 & -1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & 1 & 0 & 3 \\ 1 & 0 & 0 & 2 \\ 0 & 0 & -1 & -1 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 5 \\ -1 & 0 & 0 & -4 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

ii)
$$ {}^{gripper}T_{object} = {}^{gripper}T_{base} \cdot {}^{base}T_{object} = T_3^{-1} * T_2^{-1} * T_1$$

$$= \begin{bmatrix} 1 & 0 & 0 & -2 \\ 0 & 1 & 0 & -4 \\ 0 & 0 & 1 & -3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & 1 & 0 & 5 \\ -1 & 0 & 0 & -4 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 3 \\ -1 & 0 & 0 & -8 \\ 0 & 0 & 1 & -3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

in i)

Position is $[5, -4, 0]$

orientation $\begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$

in ii)

Position is $[3, -8, -3]$

orientation $\begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$

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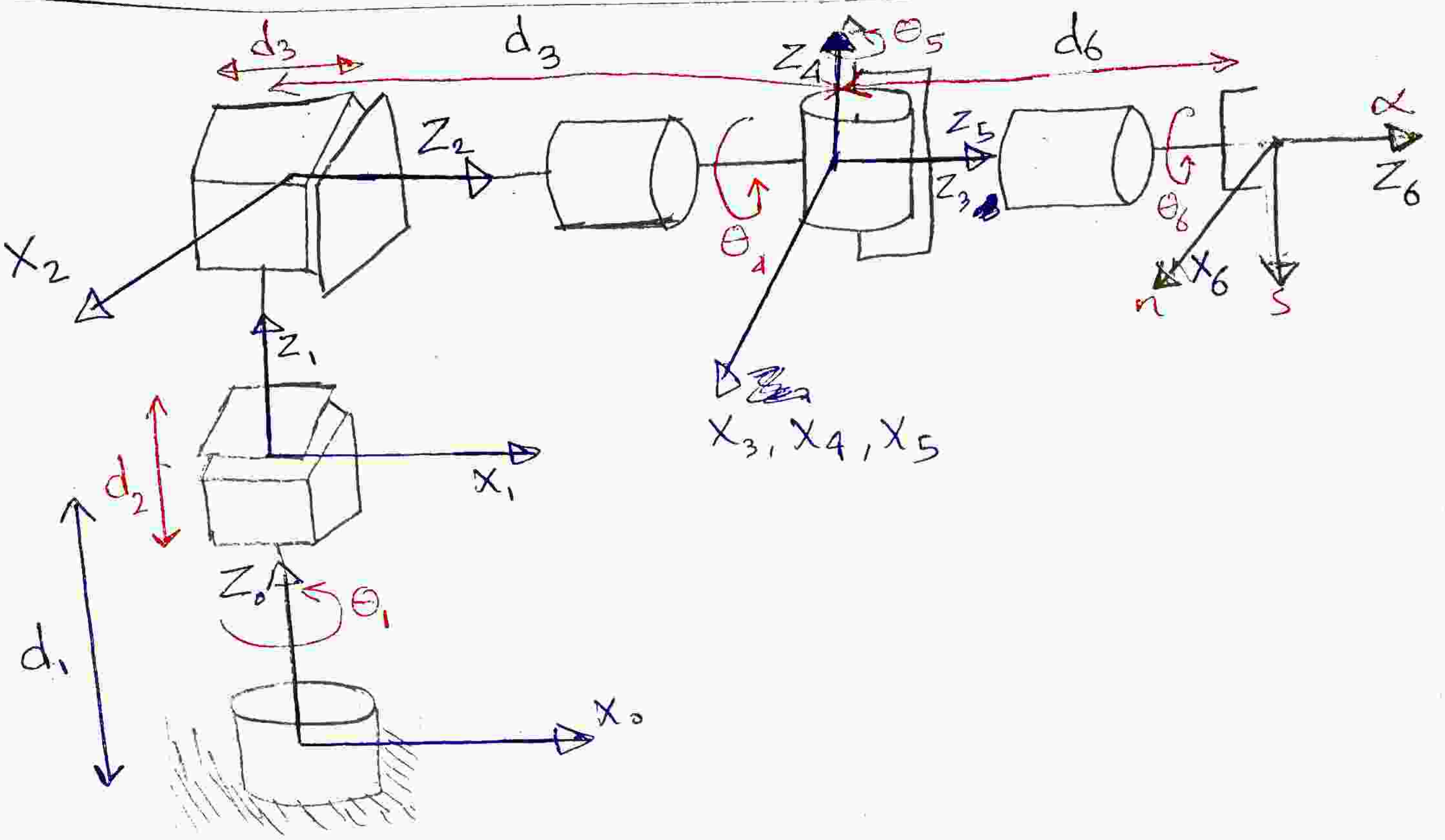
2) For the clyindrical manipulator shown, find homogeneous transformation matrix describing the forward kinematics of whole manipulator i.e, the position and orientation of end effector w.r.t the base (Apply DH: convention)

الرسمة في الصفحة القادمة



Frame	θ	d	a	α
1	θ_1^*	d_1	0	0
2	-90	d_2^*	0	-90
3	0	d_3^*	0	0
4	θ_4^*	0	0	90
5	θ_5^*	0	0	-90
6	θ_6^*	d_6	0	0

Notes

About Forward Kinematics

1) "X" الجديدة ⟸ عمودية ومتقاطعة مع Z القديمة.

2) d ⟸ المسافة بين مركز ال (frame) القديم
ونقطة تقاطع Z القديمة مع X الجديدة.

3) "a" ⟸ المسافة بين نقطة التقاطع (Z القديمة مع X الجديدة) مع ال (frame) الجديد.

4) α ⟸ الزاوية بين "Z" القديمة & "Z" الجديدة
حوالين "X" الجديدة.

5) θ ⟸ الزاوية بين "X" القديمة ، "X" الجديدة.
حوالين "Z" القديمة.

"Thanks to Ahmed Abasery"